

IN-SITU XRF MEASUREMENTS IN LUNAR SURFACE EXPLORATION USING APOLLO SAMPLES AS A STANDARD. K. E. Young¹, C. Evans², C. Allen², A. Mosie², and K.V. Hodges¹. ¹Arizona State University, School of Earth and Space Exploration, Tempe, AZ, 85287-1404 (Kelsey.E.Young@asu.edu), ²NASA Johnson Space Center, Astromaterials Research & Exploration Sciences Directorate, Houston, TX, 77058.

Introduction: Samples collected during the Apollo lunar surface missions were sampled and returned to Earth by astronauts with varying degrees of geological experience. The technology used in these EVAs, or extravehicular activities, included nothing more advanced than traditional terrestrial field instruments: rock hammer, scoop, claw tool, and sample bags. 40 years after Apollo, technology is being developed that will allow for a high-resolution geochemical map to be created in the field real-time. Handheld x-ray fluorescence (XRF) technology is one such technology. We use handheld XRF to enable a broad in-situ characterization of a geologic site of interest based on fairly rapid techniques that can be implemented by either an astronaut or a robotic explorer. The handheld XRF instrument we used for this study was the Innov-X Systems Delta XRF spectrometer.

Handheld XRF Technology: The handheld XRF spectrometer was originally developed for use in a range of industries and recently, field geologic mapping. Our goal is to evaluate this technology as a possible field/lab instrument that can be used during planetary surface exploration missions. We are developing techniques with current models of commercially-available handheld XRF spectrometer for rapid, in-situ geochemical characterization of geologic outcrops and samples.

The current handheld XRF technology is portable, robust, and simple to operate; it holds promise as a versatile field tool. In just 60 seconds, the user can obtain a rough look at the elemental abundances of a sample, for major elements that are heavier than magnesium (existing handheld XRF models cannot accurately detect and measure elements lighter than magnesium).

Using XRF on Apollo samples: Heiken et al, 2001 (*need to check reference*), has shown that XRF measurements of key elements from bulk samples can differentiate between lunar samples. Our handheld XRF instrument provides a way to quickly and roughly quantify key elements in order to differentiate between and possibly high-grade samples on the lunar surface.

By testing the handheld XRF on previously characterized lunar samples, we can evaluate how effective the instrument would have been if the Apollo astronauts had been able to use this instrument while on EVA. In this way we can determine the importance of taking geochemical instruments on future planetary

surface exploration missions, whether they be to the Moon, Mars, or an asteroid.

The lunar samples returned from the six Apollo surface missions were geochemically characterized using a number of instruments, including a laboratory XRF spectrometer. Samples were sent out to a number of labs around the country, and have since been returned to the lunar curation facilities at NASA's Johnson Space Center (JSC). 22 of these returned samples have been set aside in a collection for non-destructive tests by interested parties [1]. For this study, we use these 22 samples to compare the effectiveness and utility of handheld XRF technology. By testing the handheld XRF and comparing it to the previously obtained XRF data for these samples, we can evaluate how effective the handheld instrument is in the geochemical characterization of lunar samples. Combining this with tests in the field on Earth, we will investigate the instrument's utility in a field mapping capacity.

Methods: We collected data on a suite of well-characterized terrestrial samples to build calibration files for the major elements ([1], [3]). After the collection of the calibration data, we tested three different setups for collecting handheld XRF data from the lunar samples, all of which were done in the Returned Lunar Sample laboratory located at Johnson Space Center in Houston, TX. The first setup was established to test rock samples in the Innov-X Delta XRF testing stand which we placed on top of a lab bench. Each of the 18 rock samples was individually placed in the testing stand in an orientation that we determined to be representative of the whole sample. Measurements were taken of every face large enough to yield data (faces \leq 8mm across could not be accurately measured). In the case of samples with large phenocrysts or other heterogeneities, we took several measurements of different surfaces of the sample to make sure that we acquired all possible data. Each of the 18 hardrock samples therefore had at least 2-3 measurements taken and some had as many 6 measurements on one sample.

Four lunar soils were tested from Apollo 10, 14, 16, and 17. The methodologies for testing these with the handheld XRF had to be modified from the setup used for the hardrock samples. Two Teflon sheets were separated by approximately one inch. A hole was cut in the middle of the top Teflon sheet and a small plastic cylinder was placed in this hole. We filled the cylinder with soil so the soil was packed down. The

packed soil formed the surface where data was collected with the handheld XRF.

The third setup we used to collect data was a pressurized glovebox in the Returned Lunar Sample laboratory located at Johnson Space Center, in Houston, TX. We reran three hardrock samples tested in the first lab bench setup to evaluate the difficulties of using the handheld XRF in a glovebox.

Results: At the time that this abstract was written we have not yet completed a full data reduction and comparison of the handheld XRF data to the previously published literature on this suite of Apollo data. However, we have begun to process the XRF data, with special focus on the effect of different orientations and surface characteristics in an effort to constrain sampling techniques for the instrument. Figure 1 shows data collected from the rock samples with sawed surfaces compared with values reported in the literature and the Lunar Sample Compendium [2]. Using curves built from the calibration files, we calculated TiO_2 and FeO abundances from the spectra collected on the lunar samples (Figure 1).

Other comparisons between different faces of the same sample (representing different surface roughnesses and sample heterogeneity) are ongoing. In this way we can use the XRF data to draw parallels between rocks found at each of the Apollo landing sites.

Effects of Sample and Sampling Heterogeneities on XRF Data: Due to the early stage of development of the handheld XRF technology, we are still evaluating effects of surface and other bulk sample characteristics on the data. We have found that surface roughness, vesicularity, sample homogeneity, and distance from the sample to the detector all have an effect on the data returned from the instrument [4]. Keeping these effects in mind, we put forth methods of data collection that help to mitigate these effects.

Surface roughness had the largest effect on data returned. We collected data on smooth, sawed surfaces whenever possible as well as fresh but rough and broken surfaces. Sample homogeneity is also important to think about in data collection. Vesiculated basalts yield different results than massive basalts. Due to the 8 mm spot size of the instrument, breccias (like several of the Apollo samples we worked on) could cause inconsistencies in the data if one spot measures a different clast than a second spot. Distance from the sample to the instrument detector can also have an effect on the data because of the dispersive nature of the energy coming back to the detector from the sample [4].

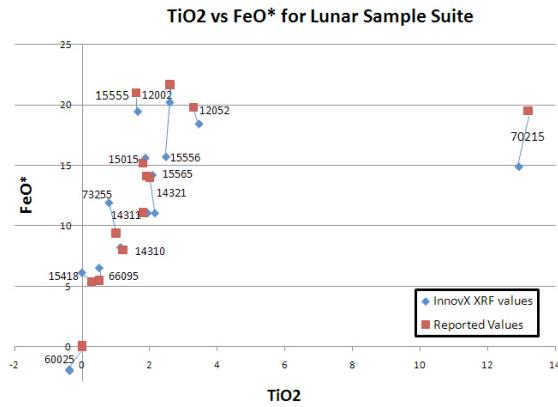
All of these effects have implications for possible sample preparation procedures in the field. Depending on what deployment mode (ie robotic, human, or habitat laboratory) is being utilized, sample surfaces should

be prepared with these considerations in mind. For example, the Pressurized Excursion Module (PEM), tested in the 2010 NASA Desert Research and Technology Field Studies field test, has a sample splitter for the astronaut crewmembers to use to create fresh surfaces, helping to eliminate the effects of surface roughness.

Future Work: We are continuing our work on the Apollo XRF data, and seek to better integrate the previous laboratory results with our handheld XRF results. Comparison of major elements between all 22 samples (including soils) will play a major role in this study and further assessments of the instrument response and operational constraints are ongoing. As with all technical instruments, understanding response under different conditions is critical for interpreting data. We will continue to characterize the effect of surface characteristics on the XRF data and work to incorporate our findings into effective instrument testing procedures for future field deployment.

We will also continue to deploy the XRF in a variety of terrestrial analog modes, including both robotic and human exploration in order to better evaluate the value the instrument provides in the field, in the lab, or as part of a robotic field assistant.

Figure 1: Preliminary TiO_2 vs FeO^* results from XRF data collected on the lunar sample suite (sawed surfaces), compared to representative values reported in the literature.



References: [1] Allen et al (2010) LPSC 2010, Abstract 1457. [2] Meyer, Charles for the Astromaterials Research & Exploration Science Office at NASA JSC (2010), The Lunar Sample Compendium. [3] Morris, Richard, Personal Communication. [4] Young et al (2010) GSA 2010, Abstract 19-10.